DESIGN OF HOT MIX ASPHALT FOR AIRFIELD PAVEMENTS USING THE SUPERPAVE GYRATORY COMPACTOR

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INTRODUCTION

Approximately 90 percent of America's paved runways are paved with hot mix asphalt (HMA). However, only a small percentage of the total HMA placed in the United States is used for airfields. Historically, HMA for airfield pavements has been designed using the Marshall mix design method. Conversely, the vast majority of non-airfield HMA pavements placed during the last 5 to 7 years have been designed using the Superpave mix design system. The percentage of HMA that is being designed using the Superpave mix design system is increasing every year. Therefore, mix design experience is being gained by HMA contractors, commercial labs, and industry personnel in the area of Superpave. Since the Marshall mix design procedure is becoming the exception to the rule, industry personnel are becoming increasingly unfamiliar with the Marshall mix design method. As such, the airfield industry needs to implement the Superpave mix design system in airfield pavements in order to benefit from the industry's experience with Superpave.

Background

Three specifications are typically used to design airfield HMA pavements. These include Item P-401 documented in the Federal Aviation Administration (FAA) Advisory Circular (AC) 150/5370-10B; the Department of Defense (DoD) Unified Facilities Guide Specification (UFGS)-32 12 15; and Engineering Brief (EB) 59A. Item P-401 and UFGS-32 12 15 are Marshall mix design specifications (Note: UFGS-32 12 15 has been updated to include a Superpave Mix Design Procedure. At the time of this research, Superpave was not included in UFGS-32 12 15). Item P-401 is utilized on most civilian airfields. The UFGS-32 12 15 is utilized to design HMA for military airfields.

EB-59A is the current Superpave mix design system allowed for airfield pavements. Using EB-59A requires approval at the FAA regional office level because it is considered a modification of standards. EB-59A was released in May 2006 and its predecessor EB-59 was released in December 2001. The relatively recent releases of the specifications and the extra approvals required in using these specifications have resulted in relatively few airfields utilizing either EB-59 or EB-59A specifications.

Problem Statement

The Marshall mix design procedure was originally developed in the 1940's for airfield pavements. While this mix design procedure has performed well for airfield and highway pavements for over 50 years there is a need to adopt the new Superpave mix design procedure for airfield pavements. An issue with the Marshall mix design method is that the compaction process does not orient the aggregate in the laboratory compacted sample the same way that it is oriented in the field. This results in a problem when attempting to conduct performance tests since the particle orientation will affect the measured results. The gyratory compactor produces aggregate orientation that is more similar to what is seen in the field.

Another issue with the Marshall method of mix design is the higher variability of test results. The proficiency sample data from the AASHTO Materials and Reference Laboratories (AMRL) over the past three years shows that the SGC provides sample air void contents with lower overall variability (standard deviation = 0.995) than samples compacted using the Marshall pedestal and hammer (standard deviation = 1.059). This lower variability should result in a more consistent design and should allow QC testing to better compare with QA testing (AMRL [1]).

A third, and likely most important, issue with the Marshall mix design process is that most state DOTs have begun using the Superpave mix design procedures. Since most asphalt work is done by the DOTs, it is becoming more difficult to find contractors and commercial laboratories having the proper accreditations with the Marshall mix design method. This problem will become much worse in the future.

Given the issues with the Marshall mix design procedure, it is desirable to adopt the Superpave mix design system for airfield pavements. Superpave was developed for highway pavements, not for airfield pavements, so some modifications to the process are likely needed prior to adopting for airfields. The Superpave mix design process should not be adopted without some research to identify the specific modifications needed for airfields.

Objective

The objective of this study was to adapt Superpave gyratory compactor procedures to design airfield HMA mixes with properties comparable with Item P-401.

Scope

In order to accomplish the project objective, the researchers carried out a number of tasks. Initially, the mix design specifications typically used to construct airfield HMA layers were critically reviewed. Comparisons between the Marshall and Superpave mix design systems were made with emphasis on identifying similarities and differences between the two systems. Next, the researchers contacted a number of experts in the area of HMA construction on airfields to discuss concerns with both the Marshall and Superpave systems. During these discussions, the researchers also identified ten airfields located throughout the US for execution of a field and laboratory study. For each of the ten identified airfields, the researchers visited and conducted a pavement performance evaluation. Additionally, cores were obtained in order to establish the in-place properties of the HMA. Materials from the original sources were obtained and included within the laboratory study. The in-place mixes were replicated using the obtained materials and compacted with both the Marshall hammer and Superpave gyratory compactor using various compactive efforts. Specimens were also prepared for performance testing, the confined repeated load permanent deformation test (or commonly called the Flow Number Test). At the conclusion of the study, the data was analyzed in order to adopt a Superpave mix design system for airfield pavements.

REVIEW OF EXISTING AIRFIELD SPECIFICATIONS

All three mix design specifications (Item P-401, UFGS 32 12 15, and Superpave) have many similarities. All include four primary steps: selection of materials, blending of selected materials, selection of optimum asphalt binder content and evaluation of moisture susceptibility. Each method has aggregate property criteria to ensure angular and clean aggregates that are properly shaped. All three specifications also ensure tough and durable aggregates; though, local agencies specify appropriate toughness and durability criteria within Superpave source properties. With respect to asphalt binders, all three allow the use of Performance Graded asphalt binders.

There are minor differences in how the aggregates can be blended. The Superpave gradation requirements allow for the most gradation options (maximum aggregate sizes). For a given maximum aggregate size gradation, use of the Superpave control points also allows for the most gradation shapes. The two historical airfield specifications are more restrictive because of the use of gradation bands. The UFGS-32 12 15 specification generally allows the finest gradations, while the Superpave specification allows the coarsest.

The biggest difference in designing HMA is that the two historical airfield specifications require laboratory compaction with the Marshall hammer, while the Superpave specification requires the Superpave gyratory compactor. Another difference is that the two airfield specifications utilize Marshall stability and flow as a proof test during mix design. Superpave does not currently include a proof test. When selecting the optimum binder content all three methods are similar in that volumetrics are used. Air voids, VMA and VFA are all directly or indirectly specified. There are slight differences in the specified volumetric requirements; the biggest of which is the use of a range in design air voids within the Marshall methods.

With respect to moisture susceptibility, all three methods utilize tensile strength ratios to provide a measure of moisture damage potential. The methods specified have slight differences, but the underlying test method is the same. Specification values only differ slightly.

In summary, the three mix design specifications have many similarities. Without question, the goal of each mix design method is to produce an HMA that is stable and durable for its intended purpose.

FIELD VISITS

After discussions with airfield experts, ten different airfields across the United States were identified and visited as part of this study. The ten selected airfields represent a range of climates, traffic levels and FAA regions. Figure 1 shows the distribution of the airfields across the country as well as the Long Term Pavement Performance (LTPP) climatic zone designations. These climatic zones are shown on Figure 1 because the research team made a concerted effort to identify airfields that had been exposed to different climates. Table 1 shows the breakdown of the airfields by traffic classification. More detailed information can be found in the final report for AAPTP 04-03, Cooley et al [2].

TEST RESULTS AND ANALYSIS

As discussed previously, the Superpave mix design system includes four primary steps: 1) materials selection; 2) selection of design aggregate gradations; 3) selection of optimum asphalt binder content; and 4) performance testing. Each of these steps is equally important to the overall mix design system; however, likely the most critical parameter needed to successfully implement a Superpave mix design system for airfield HMA pavements is the design compactive effort. The design compactive effort, or design number of gyrations, will have a direct impact on the volumetric properties of the designed mix. The volumetric properties, combined with the design compactive effort, will be related to the materials allowed within the mix (materials selection). All of these factors will have an effect on selection of a mix with acceptable properties. The following sections describe the test results and analyses conducted to develop a Superpave mix design system for airfield HMA.

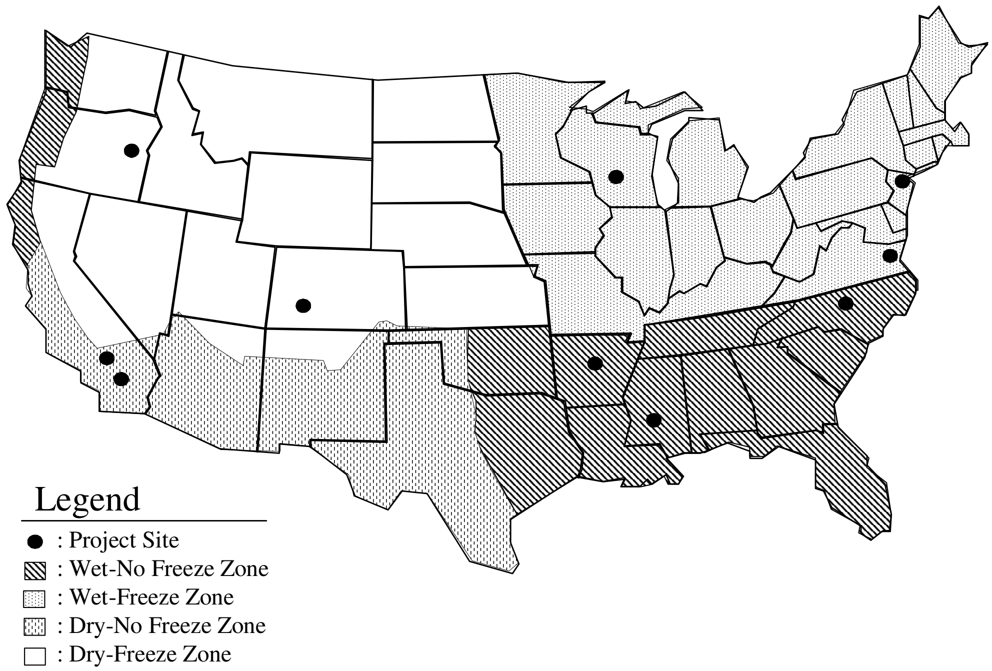

Figure 1: Locations of Visited Airfields

Table 1:
Airport Field Visit Traffic Level Designations

Traffic Level*	Light	Medium	Heavy
Airport	Jacqueline Cochran Regional Airport	Jackson-Evers International Airport	Naval Air Station - Oceana
	Mineral County Memorial Airport	Little Rock Air Force Base	Volk Field
	Oxford-Henderson Airport	Newark Liberty International Airport	
		Palm Springs International Airport	
		Spokane International Airport	

* Light traffic level airfields are considered to experience aircraft less than 60,000 lbs, medium traffic level airfields experience air traffic with tire pressures greater than 100 psi but less than 200 psi or gross aircraft weights in excess of 60,000 lbs, and the heavy traffic level receives aircraft with tire pressures in excess of 200 psi.

Selection of Design Compactive Effort

Aggregates, binder and asphalt core samples were collected from each of the visited airfield locations. In the lab, the cores were tested and the materials were combined to recreate, as closely as possible, the original mix design for each of the airfields. With the data collected during this project, the researchers investigated three different methods for selecting the appropriate design compactive effort with the Superpave gyratory compactor. The first method entailed evaluating in-place densities in a manner utilized by researchers during the development of the Marshall mix design procedure for airfields (Department of the Army [3]). The second method involved comparisons in the bulk specific gravity values of HMA mixes compacted utilizing both the Marshall hammer and Superpave gyratory compactor. The final method for determining the appropriate design compactive effort when using the Superpave gyratory compactor entailed evaluating the results of performance testing. The goal of the performance testing was to determine the asphalt binder content at which the airfield mixes began to exhibit permanent deformation tendencies.

A simple method of evaluating the various design compactive efforts utilized for the HMA at the ten airfields would be to evaluate the ultimate densities at the time of the field investigations. The term “ultimate density” indicates the in-place density of the pavement after years of trafficking. In-place densities that resulted in high voids would indicate that the in-place asphalt binder content was too low, while in place densities that resulted in low voids would indicate that the in-place asphalt binder content was too high. In order to evaluate this data, the in-place densities were divided into two data sets: one for airfields using HMA designed using the Marshall hammer and one for airfields using HMA designed with the SGC. Detailed information can be found in Cooley et al [2].

Based upon the core data, the average in-place density of all the cores from airfield pavement designs using the Marshall hammer was 96.4 percent of theoretical maximum specific gravity or 3.6 percent air voids. The average in-place density for those pavements that were performing good was 96.8 percent while those that performed poor/fair was 93.8 percent. More importantly, the in-place density for the good performing HMA layers suggests that the Item P-401 and UFGS-32 12 15 specifications for design compactive effort and design air void contents are appropriate if the intention is to select an asphalt binder content that will result in ultimate in-place densities similar to the laboratory design density.

The average in-place density for all of the cores obtained from the airfield pavements designed using the Superpave gyratory compactor was 94.4 percent of theoretical maximum specific gravity, or 5.6 percent air voids. This average air void content is 2 percent higher than the overall average observed for the Marshall hammer designed HMA layers. Though different design gyration levels were utilized for the different HMA mixes, the data suggests that the design compactive efforts utilized were too high.

The above discussion on ultimate densities reflects a very small subset of data. Because of the small subset of data, no specific conclusions were made; however, a couple of general observations are noted. Based upon the HMA layers designed with the Marshall hammer, the 75 blows per face compactive effort combined with the current design air void contents used in the Marshall mix design method, appears to accurately reflect the ultimate design density of airfield pavements. However, the design gyration levels and 4 percent design air voids used for the Superpave designed mixes did not accurately reflect the ultimate densities within the airfield pavements. These general observations suggest that the Superpave designed mixes were designed at too low of an asphalt binder content.

The second method of evaluating the proper design compactive effort with the SGC entailed comparing densities obtained from compacting samples with the Marshall hammer and Superpave gyratory compactor. Materials from each of the airfields were used to compact HMA utilizing both the Marshall hammer and Superpave gyratory compactor. Mix was compacted using 75 blows per face for all airfield mixes and 50 blows per face for six airfield mixes. Likewise, mix was also compacted using the Superpave gyratory compactor at various gyration levels for all mixes. In order to compare densities from the various compactive efforts, the laboratory density values were normalized by dividing the resulting Marshall density by the density of a companion Superpave gyratory compactor sample (at the same asphalt binder content). This resulted in a ratio of bulk specific gravities for individual mixes. A bulk specific gravity (G_{mb}) ratio of 1.0 indicates that the laboratory density resulting from the two compaction methods were equal.

There were a wide range of gyration levels that corresponded to 50 and 75 blows per face of the Marshall hammer. Figure 2 illustrates a histogram that presents the distribution of gyration levels obtained from the comparison testing. For the data representing the 50 blows per face compactive effort, gyration levels ranged from a low of 20 gyrations to a high of 49 gyrations. Roughly 67 percent of the data suggests that the gyration level corresponding to a 50 blow compactive effort is between 40 and 50 gyrations. For the 75 blow data, the gyration level ranged from a low of 32 to a high of 59. Sixty percent of the gyration levels corresponding to the density achieved by 75 blows are between 50 and 60 gyrations. Also, 50 percent of the data is between 55 and 60 gyrations.

The ten airfields visited as part of this project represent a relatively small sample of data. It would be anticipated that an equivalent number of gyrations to result in a similar density as the compactive effort provided by the Marshall hammer would be different for different aggregate types and different aggregate gradations. The range of equivalent gyration levels shown in Figure 2 seems to prove this assumption. Therefore, the data depicted in Figure 2 is considered only a sample of the overall population of gyration levels equivalent to 50 and 75 blows per face of the Marshall hammer. Assuming that the sample populations are normally distributed, confidence intervals were developed to estimate where the true average would fall.

For the 75 blows per face data depicted in Figure 2, the mean equivalent number of gyrations was 49 with a standard deviation of 10 gyrations for ten observations. Therefore, the estimated gyration level that provides an equivalent density to 75 blows per face falls between 43 and 55 gyrations at a 5 percent level of significance. This range of equivalent gyration levels is slightly lower than anticipated; however, Brown and Mallick [4] did find an average of 1.4 percent lower air voids in samples compacted to 68 gyrations in an SGC when compared to samples compacted with 75 blows per face of the Marshall hammer. Prowell and Haddock [5] found an average difference of 1.9 percent air voids when comparing 68 gyrations and 75 blows per face compactive efforts, with the SGC again providing more compaction. Therefore, the upper part of the range (near the 55 gyrations) seems an appropriate estimate for a gyration level that provides an average equivalent density as 75 blows per face of the Marshall hammer.

For the 50 blows per face data depicted in Figure 2, the mean equivalent number of gyrations was 36 with a standard deviation of 11 gyrations for six observations. Therefore, the estimated gyration level that provides an equivalent density to 50 blows per face falls between 32 and 40 gyrations.

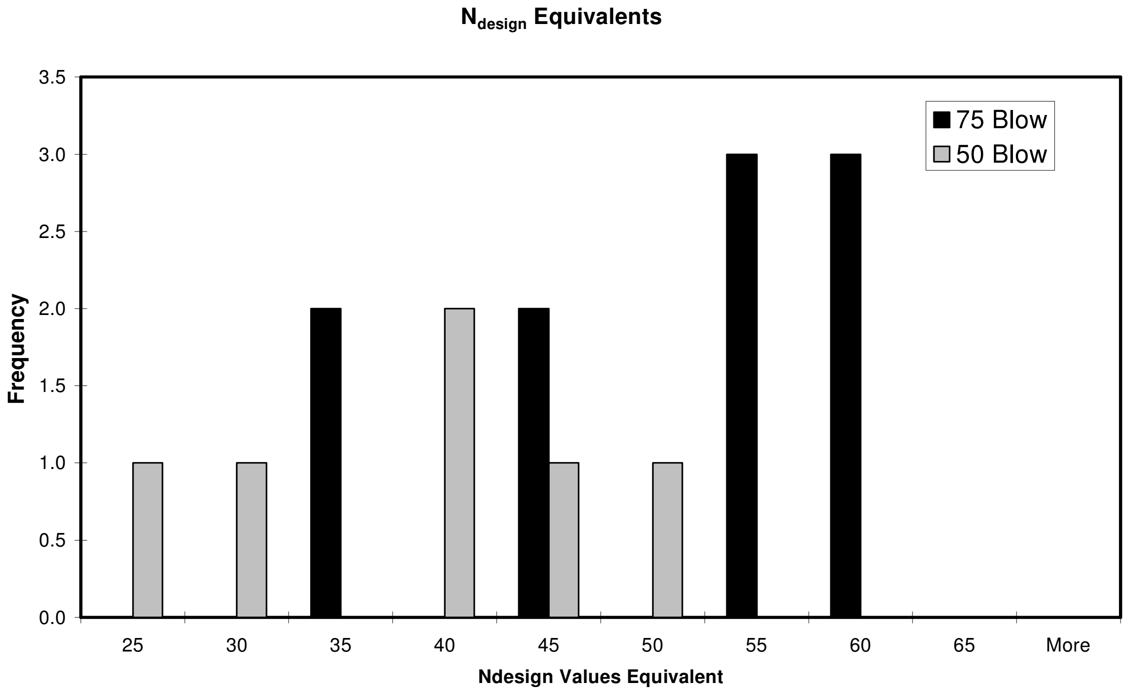

Figure 2: Histogram of N_{design} Equivalents to Marshall Compaction

The final method of evaluating the proper design compactive effort using the Superpave gyratory compactor entailed evaluating the results of the laboratory performance testing. Results from the Flow Number test are the number of loading cycles to failure. Samples were loaded to tertiary flow or 20,000 cycles, whichever came first. Samples from each airfield were tested at varying deviator stresses. The deviator stresses were selected to represent various aircraft tire pressures.

In order to evaluate the Flow Number results for the various airfields, information on the typical aircraft operating on the various airfield pavements was needed. For the civilian airfields, the Airport Master Record was obtained. The Airport Master Records contained data on the gross weights and gear configurations utilized on each airfield. LEDFAA was then used to determine the typical gross taxi weights and tire pressures for aircraft meeting the requirements depicted on the Airport Master Records. For the military airfields, the design aircraft were obtained from representatives from each respective airfield.

Results of the Flow Number tests are presented in detail for each of the ten airfields in Cooley et al [2]. The goal of the performance testing was to determine the asphalt binder content at which the various airfield mixes would begin to exhibit rutting potential. The gyration level that corresponds to the asphalt binder content at which the mixes began to exhibit rutting potential would then be considered the minimum value at which the design compactive effort (N_{design}) could be selected.

All performance testing was conducted utilizing a confining stress of 40 psi. Test temperatures for the materials from each of the airfields were based upon historical temperature data. Pavement high temperatures were obtained from LTPPBind 3.1 and utilized for performance testing.

Table 2 summarizes the estimated gyration levels determined utilizing the results of the performance testing. Design compactive efforts for Marshall designed mixes currently contained within Item P-401 are based upon a combination of aircraft gross weights or tire pressure. The design compactive efforts are differentiated based upon a gross aircraft weight of 60,000 lbs or tire pressures of 100 psi. Within Table 2 are the maximum gross taxi weights and tire pressures that were collected or calculated from data in the LEDFAA software.

Table 2:
Estimated N_{design} Values Based upon Performance Testing

Airfield	Max. Gross Wt. (lbs)	Max. Gross Wt. per Tire (lbs)	Tire Pressure (psi)	Estimated N_{design} Value
Jacqueline Cochran Regional Airport (TRM)	20,000	10,000	75	50
Mineral County Memorial Airport (C24)	12,500	6,250	90	50
Oxford-Henderson Airport (KHNZ)	30,000	15,000	75	35
Little Rock Air Force Base (LRF)	155,000	38,750	105	50
Naval Air Station Oceana* (NTU)	66,000	33,000	240	75
Volk Field (VOK)	42,500	21,250	215	75
Jackson International Airport (JAN)	890,000	55,625	200	35
Newark Liberty International Airport (EWR)	873,000	54,563	200	35
Palm Springs International Airport (PSP)	800,000	52,500	200	N/A
Spokane International Airport (GEG)	400,000	100,000	200	N/A

N/A – Insufficient Data to Estimate Appropriate N_{design} Value
* Evaluated mix rutted in the field.
** LEDFAA provided Design Aircraft tire pressure and Main Gear Wheel Numbers used to calculate the Maximum Gross Weight per Tire except for LRF, NTV and VOK
*** all Gross Taxi Weights are from Master Airport list except for LRF, NTV and VOK

The estimated design gyration levels shown in Table 2 are interesting. Estimated design gyration levels ranged from a low of 35 gyrations to a high of 75 gyrations. Based upon the performance testing, none of the airfields would have required design gyration levels above 75 gyrations. The low estimated design gyration level of 35 is interesting as there is little to no experience with mixtures designed using such a low N_{design}. However, the 35 gyrations does fall within the range of gyration levels found equivalent to 50 blows of the Marshall hammer.

The three general aviation mixtures (TRM, C24, and KHNZ) had estimated design compactive efforts ranging from 35 to 50. Two of the three had an estimated design compactive effort of 50 (TRM and C24) while the third had an estimated design compactive effort of 35 (KHNZ). Based upon Item P-401, the appropriate design compactive effort for these three mixes would have been 50 blows per face of the Marshall hammer. Based upon the SGC gyration range equivalent to a 50 blow Marshall design, which was 32 to 40 gyrations, this data suggests that an N_{design} value of 40 would be appropriate for general aviation airfields.

Another interesting observation from Table 2 is that the three military airfields, LRF, NTU and VOK, had somewhat similar estimated design gyration levels ranging from 50 to 75 gyrations. Two of these military airfields also had the highest tire pressures anticipated to traffic the pavements with NTU having 240 psi tires and VOK having 215 psi tires. The 75 gyration levels shown in Table 2 are higher than the equivalent range of design gyrations (43 to 55) corresponding to 75 blows of the Marshall hammer that was found in this project. This would indicate that the 75 blow per face design compactive effort may not have been appropriate for these projects. Additionally, airfields, especially military, in which aircraft having very high tire pressures will need to be designed at higher design gyrations than at typical commercial airfields.

The final grouping of data was for commercial airfields, which included JAN, EWR, PSP and GEG. Design tire pressures for all four of these airfields were 200 psi. Unfortunately, the performance testing data from two of these airfields (PSP and GEG) did not pass the test of reasonableness. For the remaining two airfields, the estimated design gyration level was 35 gyrations. As stated previously, this level of design gyrations corresponds to a 50 blow Marshall design compactive effort which experience suggests is unreasonable. Also, as detailed in Reference [1] there were concerns about data determined from the JAN and EWR airports.

Discussion on Selection of Design Gyration Levels for Airfield Superpave Mix Designs

The first method looked at the ultimate densities of the ten airfield pavements included within this project. Results from this analysis suggested that airfield mixes that had been designed using the Superpave gyratory compactor had been designed at N_{design} values that were too high. The ultimate densities of these pavements were all below the design densities, suggesting a lack of asphalt binder in the mixes.

The second method for evaluating the appropriate N_{design} levels involved comparing the density that resulted from Marshall hammer and SGC compaction. As expected, there was no single gyration level that was exactly equal to either 50 blows per face or 75 blows per face of the Marshall hammer. Therefore, ranges of gyration levels equivalent to each Marshall hammer compactive effort were developed using materials from the ten airfields visited during this project. Based upon the data, the gyration level equivalent to 50 blows per face of the Marshall hammer was somewhere between 32 and 40 gyrations. The gyration level equivalent to 75 blows per face of the Marshall hammer was somewhere between 43 and 55 gyrations.

The final method of evaluating the data was to analyze the results of the performance testing of mixes having different asphalt binder contents. The goal of this testing was to maximize durability, while minimizing rutting potential. For general aviation types of airfields which operate light aircraft with relatively low tire pressures, the analysis of the performance data indicated that an appropriate N_{design} value would be approximately 40. This value falls within the range of gyration levels equivalent to 50 blows per face of the Marshall hammer and seems reasonable. For the military type of airfields which operate aircraft with relatively high tire pressures, the analysis of performance data suggested that an appropriate N_{design} value of approximately 75 would be appropriate. However, the data did also indicate that for military airfields in which aircraft having relatively lower tire pressures, a lower N_{design} value would also be appropriate. Unfortunately, the data for commercial type airfields was inconclusive.

As shown in Table 2, selection of design gyration levels appear to be more related to tire pressures than aircraft gross weights. For instance, the maximum weight of aircrafts at LRF is 155,000 lbs. The estimated N_{design} value for this airfield was 50 gyrations. However, at NTU, the maximum gross weight of aircraft was 33,000 lbs. The estimated N_{design} value for this airfield was 75 gyrations. The big difference between these two airfields is that the aircraft operating at NTV had tire pressures of 240 psi, while at LRF the tire pressures were 105 psi. Therefore, tire pressures should be included within the criteria for selection of the proper N_{design} value when designing HMA for airfield applications.

Table 3 provides N_{design} values based upon the results of this research. The only criterion for selecting the appropriate N_{design} value included within Table 3 is tire pressure. Table 2 indicated no relevance of maximum gross taxi weight on selection of the design gyration value. This is not to state the aircraft weight is not important, because aircraft weight is very important in pavement thickness design. The design gyration levels of 40 and 55 were selected because they are roughly equivalent to 50 and 75 blows per face of the Marshall hammer, respectively. The 70 gyration design compactive effort was selected in order to provide a more rut resistant HMA mix at airfields that will be subjected to high tire pressures.

Table 3:
N_{design} Values Based Upon Research

Tire Pressure, psi	N_{design}
Less than 100	40
100 to 200	55
More than 200	70

The N_{design} values shown in Table 3, specifically the gyration level of 40, are somewhat lower than was expected at the onset of this project. There is very little experience with HMA mixes designed with a compactive effort as low as 40 gyrations. The possibility for the lower than expected numbers could be that the researchers purposely developed a research approach that would maximize the durability of HMA mixes designed with the SGC. However, it is still very important to minimize the rutting potential of airfield HMA mixes. Rutting can cause directional control problems or lead to the increased potential for hydroplaning during rain events; therefore, the researchers will recommend a slightly different table of design gyration levels in which experience indicates that the mixes will be durable and rut resistant. Table 4 presents the recommended N_{design} values to be used for designing airfield HMA using the Superpave mix design method.

Table 4:
Recommended N_{design} Values for Designing Airfield Mixes

Tire Pressure, psi	N_{design}
Less than 100	50
100 to 200	65
More than 200	80

Design gyration values within Table 4 are 10 gyrations higher for each tire pressure category. These additional gyrations were added to each category to minimize the potential for rutting while still providing durability. The 50 gyration design level is a slightly higher compactive effort than 50 blows per face of the Marshall hammer. The 65 gyration level is slightly higher compactive effort than 75 blows per face of the Marshall hammer as found in this project, while the 80 gyration level was added to specifically address airfield pavements that experience high tire pressure.

Evaluation of Gradation Requirements

Unfortunately, the time and budget constraints for AAPTP 04-03 did not allow for a complete evaluation of the influence of gradation characteristics on airfield Superpave designed mixes. Because the durability of airfield pavements is of paramount importance, there was concern by the research team with coarser gradations currently allowed within the highway version of the Superpave mix design system. Cooley, Prowell and Brown [5] have shown that mixes having coarser gradations tend to be more permeable than mixes having finer gradation shapes at a given in-place density (or air voids). Permeable pavement layers can lead to durability problems during the life of the pavement. There are two aspects of a pavement that can be adversely affected by permeability, infiltration of air and water. Kumar and Goetz [6] have shown a direct relationship between permeability and asphalt age hardening. When air (oxygen) reacts with the asphalt binder within HMA, the binder becomes more brittle (age hardens) which increases the potential for both cracking and raveling. Both of these distresses can lead to FOD. Likewise, the infiltration of water into a pavement layer can lead to moisture damage. Moisture damage can reduce the structural capacity of a pavement layer as well as lead to raveling.

Because of the concerns with coarser gradations, an experiment was carried out that was intended to evaluate the effect of gradation on the permeability characteristics of HMA mixes. The intent of altering the gradations of airfield mixes was to evaluate the relationship between permeability and density. This evaluation allowed the research team to make recommendations on the applicability of the gradation requirements within the highway version of the Superpave mix design procedure for airfields. Because durability is the primary distress mechanism on airfield pavements, limiting the potential for permeable pavements was important. Five of the ten airfield mixes were selected for this experiment that had sufficient materials for the additional testing. The selected airfields were Oceana Naval Air Station (NTV), Oxford-Henderson Airport (KHNZ), Mineral County International Airport (C24), Volk Field (VOK), and Jackson-Evers International Airport (JAN). Because each of the design gradations was relatively fine, the developed gradations were coarser than the design gradation. Of the five airfield mixes, three are considered a 12.5 mm nominal maximum aggregate size gradation (NMAS), one a 9.5 mm NMAS and one a 19.0 mm NMAS according to the Superpave definition of NMAS.

The results of this experiment suggest that coarser gradations lead to an increased potential for permeability problems within a constructed airfield pavement.

In summary, the results of the experiment suggest that mixes having coarser gradations do have greater potential for being permeable. The data suggests that the lower control point for the highway version of the Superpave mix design system should be increased in order to minimize the potential for permeable pavements. This is important because durability is a major concern on airfield pavements. Pavements that are permeable have an increased potential for cracking, raveling and moisture damage. Based on the data, for HMA designed for airfield pavements using the Superpave mix design system, the lower control points should be increased by 5 percent on the No. 8 sieve.

Increasing the lower control point on the No. 8 sieve by 5 percent, the revised Superpave gradation requirements very closely match the current P-401 and UFGS-32 12 15 gradation requirements on the No. 8 sieve. Therefore, there is no reason to change the current airfield

HMA gradation requirements when designing airfield HMA mixes using Superpave methods. However, the researchers have consolidated the Item P-401 and UFGS-32 12 15 gradation requirements in order to provide a single gradation band for each maximum aggregate size gradation. The recommended gradation requirements are presented in Table 5.

Table 5:
Recommended Gradation Requirements for Superpave Designed Airfield HMA

Sieve Size	Percentage by Weight Passing Sieves			
U.S. (mm)	1½"max	1" max	3/4" max	½" max
1-1/2 (37.5)	100	---	---	---
1 (25.0)	86-98	100	---	---
¾ (19.0)	68-93	76-97	100	---
½ (12.5)	57-81	67-87	77-98	100
3/8 (9.5)	49-69	58-80	68-89	77-98
No. 4 (4.75)	34-54	42-62	50-70	58-78
No. 8 (2.36)	22-42	29-48	35-55	40-60
No. 16 (1.18)	13-33	19-40	23-34	27-47
No. 30 (0.600)	8-24	12-30	16-34	18-36
No. 50 (0.300)	6-18	8-22	12-28	11-25
No. 100 (0.150)	4-12	6-17	7-20	6-18
No. 200 (0.075)	3-6	3-6	3-6	3-6

Material Requirements

Materials used in the design of dense-graded HMA include coarse aggregates, fine aggregates, asphalt binder, and other materials that may be required to meet the mix design specifications. No specific research was conducted as part of this study to evaluate the influence of material properties on HMA performance. However, comparisons between the historical mix design methods and the Superpave mix design method suggested that the aggregate quality characteristics were actually similar between the methods. For coarse aggregates, all three mix design specifications (Item P-401, UFGS-32 12 15 and Superpave) had criteria for aggregate angularity, and shape. The primary difference was that the two airfield mix design specifications had criteria for coarse aggregate toughness, soundness and cleanliness. The Superpave mix design system allows individual agencies (or states) to develop the criteria for these three aggregate quality characteristics.

Fine aggregate quality characteristics were also similar. All three mix design specifications have requirements for the angularity and cleanliness of the fine aggregates. Item P-401 does have requirements for toughness and soundness, while UFGS-32 12 15 and Superpave do not.

Though the aggregate quality characteristics specified between the three mix design specifications are similar, the values do differ. This is specifically true for the coarse aggregate angularity. Item P-401 includes two specification values for the percent fractured faces: one for HMA being designed to carry aircraft with gross weights greater than 60,000 lbs and one for those airfields that will carry lighter aircraft. As would be expected, the more stringent specification value is for the airfield pavements that will carry the heavier aircraft. The specification value for these airfields is a minimum of 70 percent of coarse aggregates have two or more fractured faces, while the minimum percent two or more fractured faces for the lighter aircraft is 50 percent. UFGS-32 12 15 contains only a single requirement for two or more fractured faces which is a minimum of 75 percent. The specified aggregate requirements within the Superpave mix design system are based upon anticipated traffic and tend to be higher than the two historical airfield mix design specifications. At very low highway traffic levels, the

Superpave requirements are similar to the two airfield specification requirements in that the minimum percent of coarse aggregate particles with one fractured face is 55 and 70 percent. However, at medium traffic levels, the fractured face percentages increase to 85 percent with one fractured face and 85 percent with two or more fractured faces (85/80). This requirement is more stringent than either of the two airfield mix design specifications. As traffic increases, the angularity specification values increase to 95/90 for high traffic and 100/100 and very high traffic.

Requirements for the fine aggregates are generally very similar between the three mix design specifications. The primary difference is that the two historical airfield mix design specifications have requirements for a maximum percentage of natural sand, while the Superpave specification does not. Uncompacted voids in the fine aggregate is specified within the Superpave mix design system. UFGS-32 12 15 actually specified both a maximum percentage of natural sand and the uncompacted voids in the fine aggregates.

The toughness and soundness aggregate quality characteristics are included within both airfield mix design specifications, while within the Superpave mix design system it is considered a source property in which individual agencies develop specification values. However, notes within both Item P-401 and UFGS-32 12 15 state the Engineer can allow aggregates that don't meet the toughness requirements if there is a history of the aggregate source performing well within pavements.

The final aggregate quality characteristic included within the three mix design specifications is cleanliness. Item P-401 utilizes Atterberg limits while UFGS-32 12 15 and Superpave utilize sand equivalency.

As stated previously, no specific research was conducted to evaluate the aggregate quality characteristics during this project. However, any mix design system needs aggregate quality requirements in order to provide a quality HMA. Therefore, recommendations were developed for aggregate quality. Table 6 presents the recommended aggregate specification values for the design of airfield HMA using the Superpave specification. This table purposefully does not include requirements for toughness and soundness as these will be maintained within the recommended guide specification in the same method as currently specified.

Table 6:
Aggregate Requirements for Airfield Superpave Design HMA

N_{design}	Min. % Fractured Faces*	Uncomp. Voids of Fine Agg., % Min.	Max. % Natural Sand	Max. % Flat and Elongated Particles (5:1)	Min. Sand Equivalency
50	85/80	40	20	10	40
65	95/90	45	15	10	40
80	95/95	45	15	10	50

Commercial mineral fillers added to an HMA are addressed similarly within both historical airfield mix design methods. Both state that any commercial mineral fillers should meet the requirements of ASTM D242. This requirement will not be changed.

Selection of Optimum Asphalt Binder Content

All three mix design specifications rely on volumetric properties to select the optimum asphalt binder content during design. The volumetric properties of air voids, VMA, and VFA are included within all three design specifications. Item P-401 and UFGS-32 12 15 both allow the designer to select the optimum asphalt binder content based upon a range of air voids, while the current Superpave mix design system requires selection of optimum asphalt content at 4.0 percent voids.

A volumetric property in which there are differences between the two historical airfield mix design specifications is VMA. Item P-401 requires 1 percent higher VMA for a given maximum aggregate size gradation compared to UFGS-32 12 15. The VMA requirements in the Superpave mix design system matches UFGS-32 12 15.

No specific research was conducted in order to select appropriate volumetric properties; therefore, similar to the aggregate properties, the researchers are recommending volumetric properties based upon experience. Table 7 presents the recommended volumetric criteria for designing airfield HMA using the Superpave gyratory compactor. Within this table, optimum asphalt content is selected based upon the same volumetric properties as outlined in all three mix design specifications: air voids, VMA, and VFA. A single design air void content of 4 percent was selected. This air void content is consistent with the current Superpave mix design system. The recommended VMA values are consistent with the values currently specified within UFGS-32 12 15 and the Superpave mix design system. Voids filled with asphalt values are based upon the VMA and air void criteria. Also contained within Table 7 is a volumetric requirement for the percent theoretical maximum density at the initial number of gyrations. The initial number of gyrations for the less than 100, 100 to 200 and greater than 200 psi tire pressure categories are 6, 7 and 7, respectively. The final specification values show within Table 7 are for dust-to-binder ratio. This is calculated by dividing the percent minus No. 200 from the gradation (percent by mass) by the effective asphalt binder content of the mix.

Table 7:
Volumetric Properties For Selecting Optimum Asphalt Binder

Tire Pressure, psi	N_{design}	Required Relative Density, Percent of Theoretical Maximum Specific Gravity		Voids in the Mineral Aggregate (VMA), Percent Minimum Maximum Aggregate Size, mm				Voids Filled with Asphalt (VFA) Range, Percent	Dust-to-Binder Ratio Range
		$N_{initial}$	N_{design}	1 ½	1	¾	½		
<100	50	≤90.5	96.0	12.0	13.0	14.0	15.0	70-80	0.6-1.2
100 to 200	65	≤90.5	96.0	12.0	13.0	14.0	15.0	65-78	0.6-1.2
>200	80	≤89.0	96.0	12.0	13.0	14.0	15.0	65-75	0.6-1.2

Performance Testing

Again, no specific research was conducted within this study to develop an appropriate performance test for HMA mixes design in accordance with the airfield Superpave mix design method. Moisture susceptibility testing should be conducted in order to evaluate the potential for moisture damage in the designed mix. ASTM D4867 should be used for this testing. A minimum tensile strength ratio of 80 percent is recommended for samples prepared with the Superpave gyratory compactor.

CONCLUSIONS

Based upon the activities conducted within this research project, the following conclusions are provided:

- There are many similarities between the historical airfield mix design specifications, Item P-401 and UFGS-32 12 15, and the highways version of the Superpave mix design system.
- For the ten airfields evaluated within this research, the Marshall hammer design compactive effort appeared to more accurately reflect the ultimate density of pavement layers than did the Superpave gyratory compactor. The data suggested that design compactive efforts utilized for the different HMA pavement layers were too high when using the Superpave gyratory compactor.
- Based upon the obtained materials from the original sources for the ten airfields, 43 to 55 gyrations provide an equivalent compactive effort to 75 blows per face of the Marshall hammer, while 32 to 40 gyrations provides an equivalent compactive effort to 50 blows per face of the Marshall hammer.
- The repeated load permanent deformation test (Flow Number) test was utilized in order to identify the asphalt binder content at which the recreated HMA from each of the ten airfields would begin to exhibit high rutting potential. This asphalt binder content was then utilized to determine the gyration level that would result in 4 percent air voids. A design gyration level (N_{design}) was then estimated that would maximize the durability of HMA while minimizing rut potential. Estimated N_{design} values for the ten airfield HMA mixtures ranged from a low of 35 to a high of 75 gyrations.
- Estimated N_{design} values were more related to the design tire pressures than the maximum gross aircraft weights.
- Results of permeability testing conducted on HMA mixtures having varying gradations suggested that the gradation requirements contained within the highways version of the Superpave mix design allowed gradations that had potential for permeable pavement layers.
- Results from permeability testing suggested that the lower control points contained in the gradation requirements of the highways version of the Superpave mix design method should be increased by 5 percent passing the #8 sieve.

RECOMMENDATIONS

Based upon the conclusions discussed above, specification requirements for using the Superpave gyratory compactor were developed and are recommended. Table 7 presents the recommended volumetric properties. These specification requirements are presented in whole within Volume II of the original research report. It is recommended that these requirements be evaluated by a number of persons that are experienced with both airfield pavement construction and the highways version of the Superpave mix design procedure. The recommended Superpave mix design method for airfields should be utilized to design HMA for several demonstration projects in order to verify that HMA mix designed using the recommended procedure can be properly produced. Currently, there are a number of research efforts for adapting the Superpave mix design method for airfields; researchers from these various efforts should meet in order to discuss the recommended procedure and share research results in an effort to improve the mix design procedure.

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